

Atmospheric Physics II

4e. Determine the processes associated with cloud formation and dissipation.



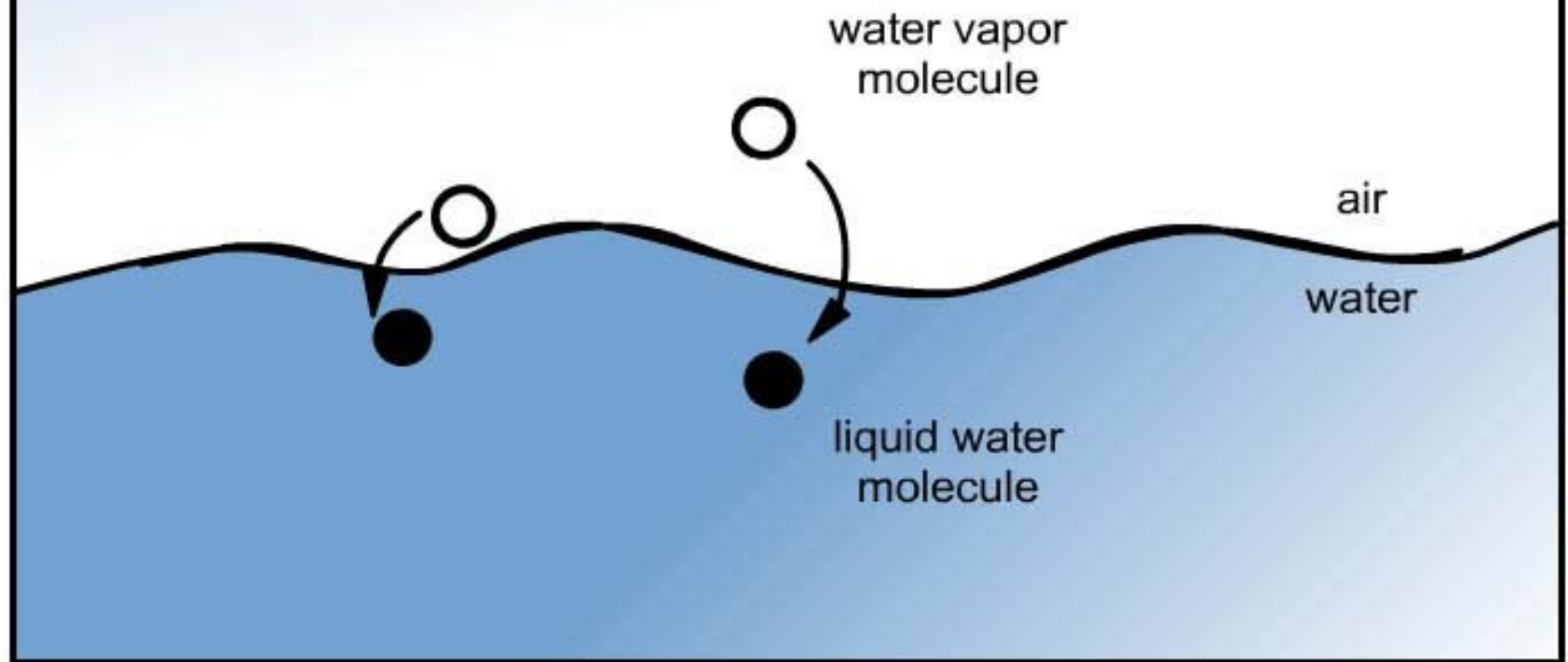
Cloud microphysics

- Clouds form when the atmosphere is saturated.
 - Saturation occurs when the air holds the maximum amount of water vapor possible.
 - At saturation the temperature is equal to the dew point temperature ($T = T_d$); the specific humidity is equal to the saturation specific humidity $q = q_s$; and the relative humidity is 100%.

Cloud microphysics

- Saturation is a state of equilibrium.
 - Water is constantly evaporating and condensing .
 - The amount of water vapor molecules in the air is constant, but the actual molecules are constantly changing their state (or phase).

Saturation



Determine the processes associated with cloud formation and dissipation

Cloud microphysics

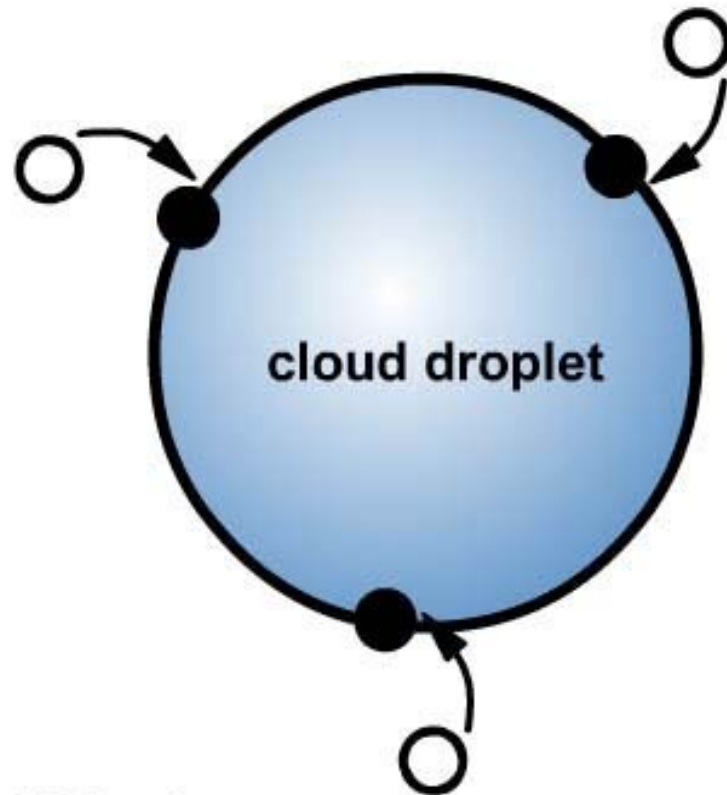
- Cloud Condensation Nuclei (CCN) are necessary for water vapor to convert to liquid.
 - CCN are particles on which water vapor condenses to form water droplets.
 - The most effective particles are hygroscopic (water attracting) and water soluble.
 - If the CCN are water soluble, the resulting water droplet is not pure water but a solution.
 - The concentration of the solution (mass of CCN to volume of water in the droplet) depends upon the size of the CCN and the amount of vapor which has condensed on to it (i.e., the volume of the droplet).



Cloud microphysics

- Initiation and growth of cloud droplets.
 - Cloud droplets are initiated by the condensation of water vapor on CCN.
 - Cloud droplets continue to grow by water vapor condensing onto the droplet
 -
 - The amount of growth by condensation is governed by the difference in saturation vapor pressures (e_s) between the droplet and its surrounding environment •

Cloud Droplet Growth by Condensation

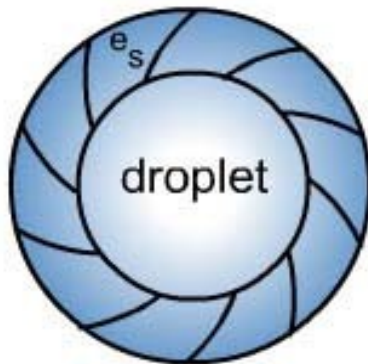


Water Vapor Molecule

Comparisons between e_s of a droplet and its Environment

The environment and the air surrounding the droplet are assumed to be saturated

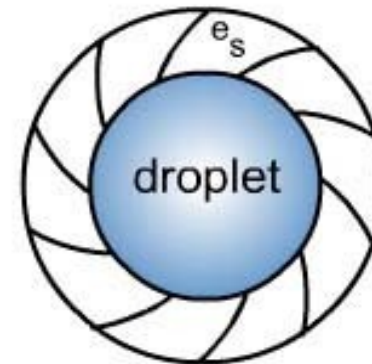
$e_{s \text{ environment}}$



$e_{s \text{ env}} > e_{s \text{ droplet}}$

The droplet grows by condensation

$e_{s \text{ environment}}$



$e_{s \text{ env}} < e_{s \text{ droplet}}$

The droplet shrinks by evaporation

Cloud microphysics.

- The air immediately surrounding all the droplets is said to be saturated ($e = e_s$).
- Each droplet will have a different e_s based upon its concentration (solute effect) and its size (curvature effect).
 - Solute effect - Droplets consisting of higher concentrations of solution will have a lower e_s than more pure droplets.
 - Curvature effect - Small droplets (tightly curved) will have a larger e_s than big droplets (flatter surface).

Cloud microphysics

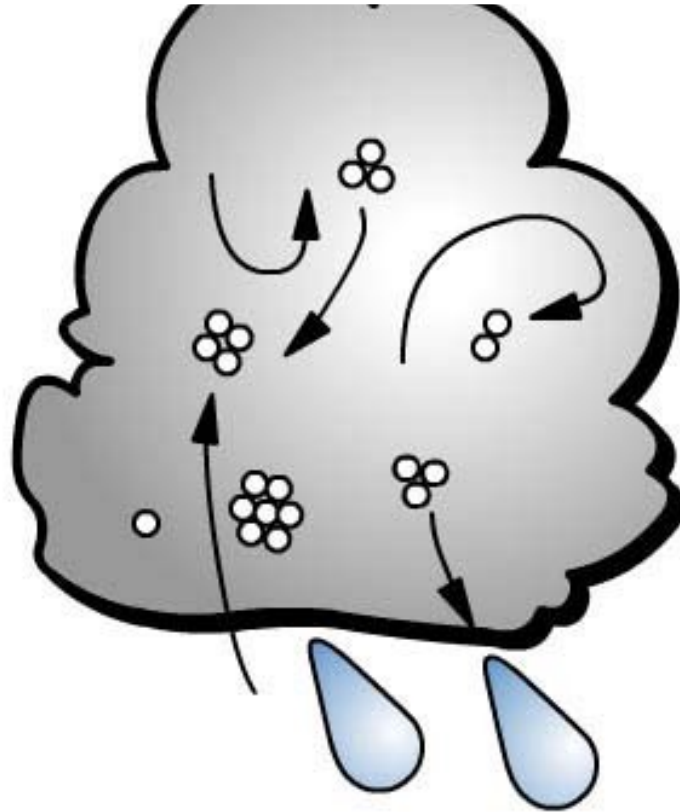
- Droplets with lower e_s
will grow at the expense of those with higher e_s . (Flow is from higher to lower pressure).
- In the atmosphere, the solute effect and the curvature effect tend to counteract each other.

Cloud microphysics

– Collision-Coalescence

- Once droplets grow large enough to fall, they can collide with other droplets and merge to form even larger droplets.
- Coalescence means the droplets which collide with each other and stick together.
- This is an method of droplet growth (much more efficient than condensation).
- While this process is occurring, the droplets still grow by condensation.

COLLISION - COALESCENCE



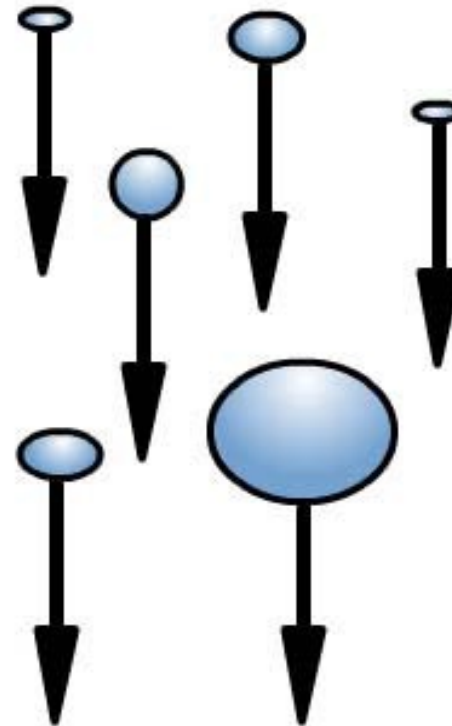
Cloud microphysics

- Four different conditions affect the efficiency of the collision-coalescence process:
 - Residence time in the cloud. The longer the droplet remains in the cloud the greater chance it has to interact with other droplets.
 - The amount of liquid water in the cloud. (The larger the better.)
 - Thick clouds provide a greater distance for the droplet to fall and hit other droplets.
 - » Updrafts within the cloud can bring droplets to upper portions of the cloud.

Saturation



Residence time
in cloud



Variable fall
velocities

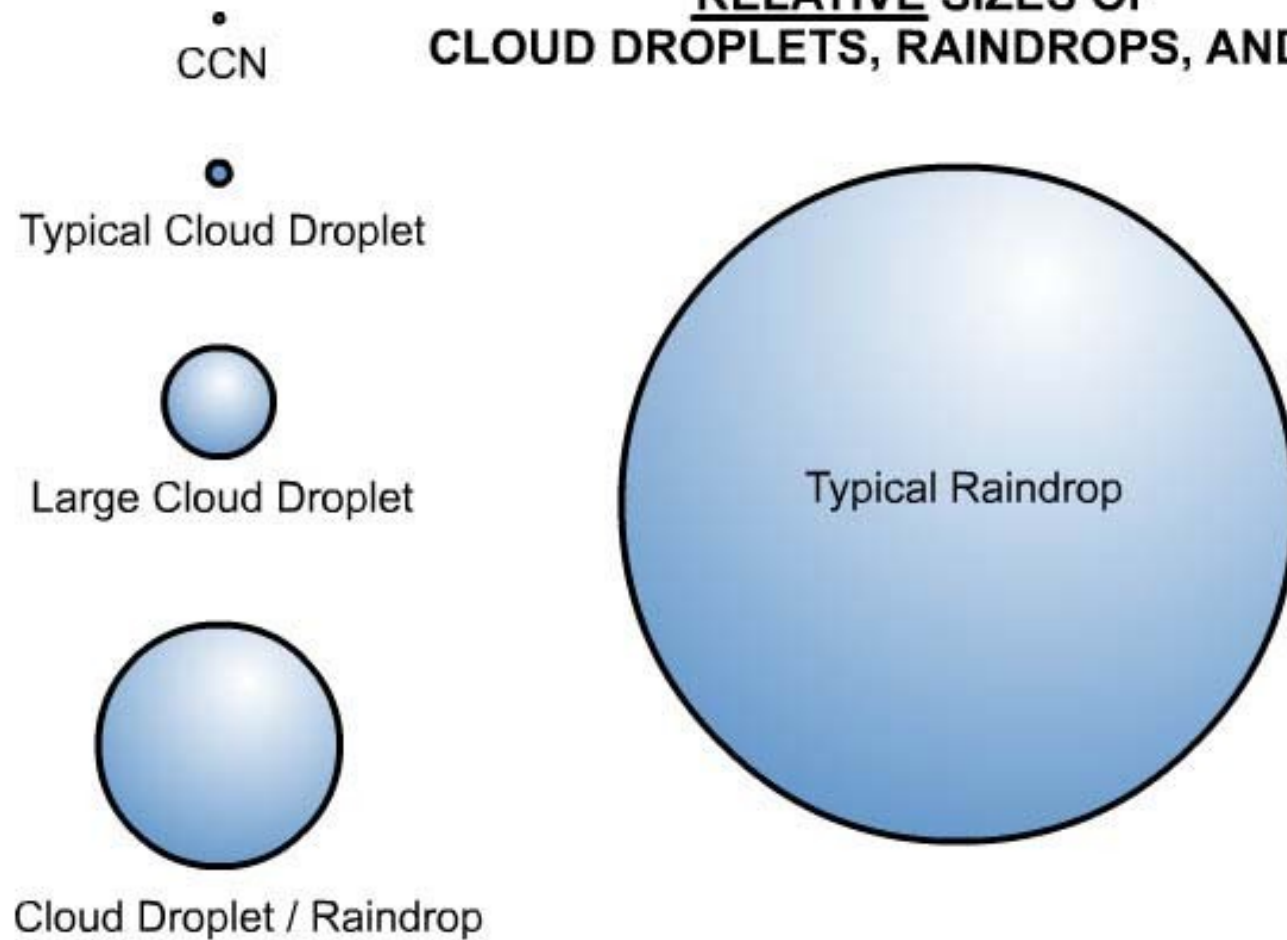
Factors Affecting Collision-Coalescence Efficiency

Cloud microphysics

- Variable droplet fall velocities. If droplets are falling at different rates, the faster ones will catch up and collide with the slower ones.
 - Larger droplets fall at a faster rate than smaller ones.
 - A wide spectrum of sizes is indicative of variable fall velocities.
- The droplet's electric charge and the cloud's electric field.



RELATIVE SIZES OF CLOUD DROPLETS, RAINDROPS, AND CCN



Cloud microphysics

- Initiation and growth of ice crystals
 - IN - ice nuclei (similar to CCN) are necessary for liquid or vapor to form ice crystals.
 - If no IN are present in the air, water will instantaneously freeze (form ice) when temperatures reach -40°C ($= -40^{\circ}\text{F}$) or below. Another name for this process is “spontaneous nucleation”.
 - Water droplets at temperatures below 0°C are called supercooled.
 - They exist in the liquid state.
 - If they encounter an ice crystal, they will automatically freeze on to the ice crystal.
 - Supercooled water droplets are very common at temperatures above -10°C .

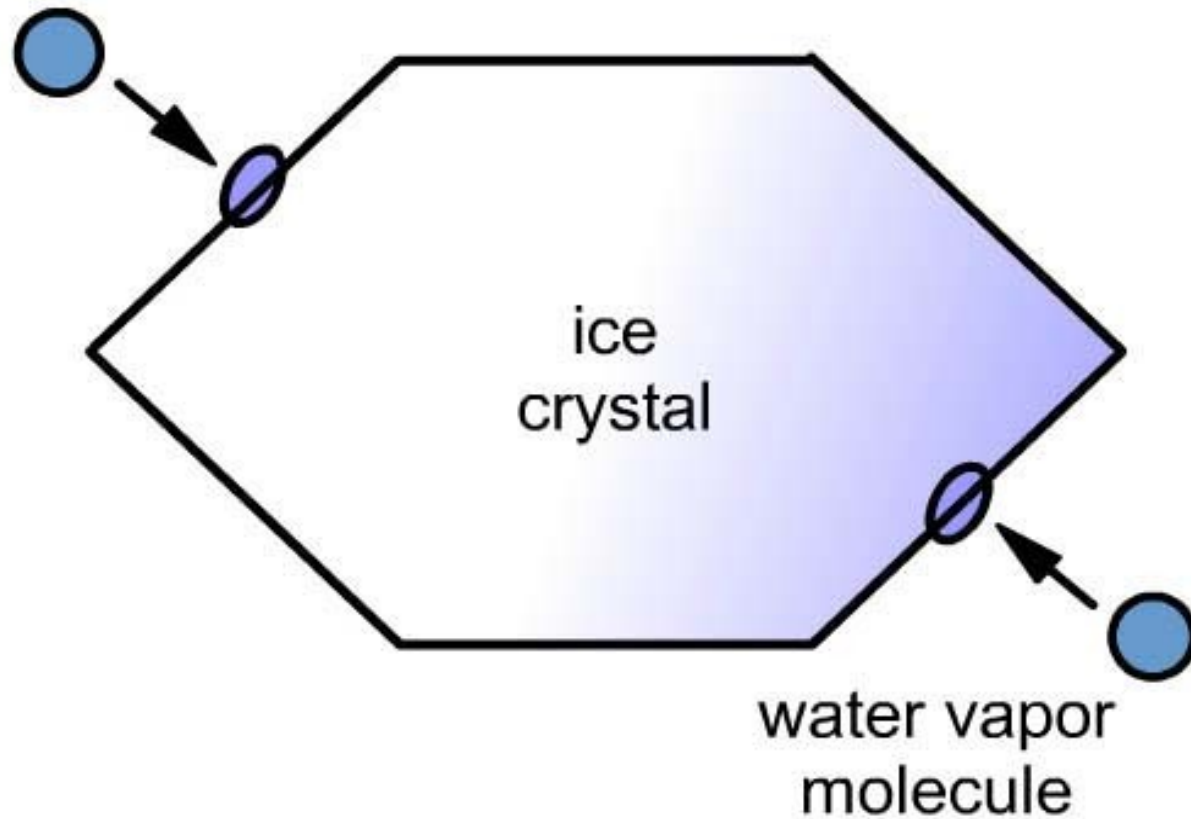
Cloud microphysics

- Typical natural IN are clay particles. (Silver Iodide (AgI) is used as an artificial IN in cloud seeding operations). Has a similar crystalline structure as ice.

Cloud microphysics

- Once a crystal is formed it grows by DEPOSITION (conversion of vapor to ice).
 - The saturation vapor pressure over ice is less than that over water ($e_{si} < e_{sw}$).
Flow is from high to low.
 - Ice crystals will grow at the expense of water droplets.

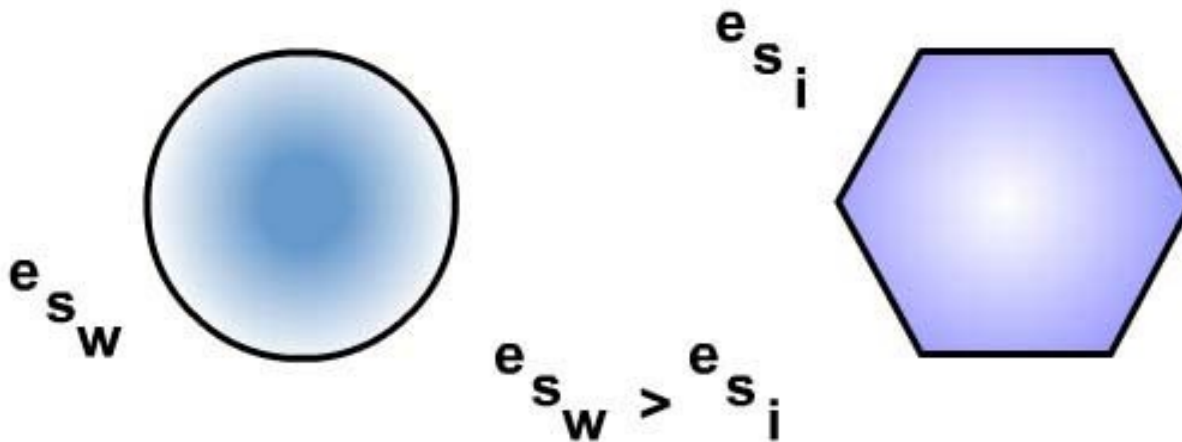
Growth by Deposition



Interaction of Cloud Droplets and Ice Crystals

shrinks by
evaporation

grows by
deposition

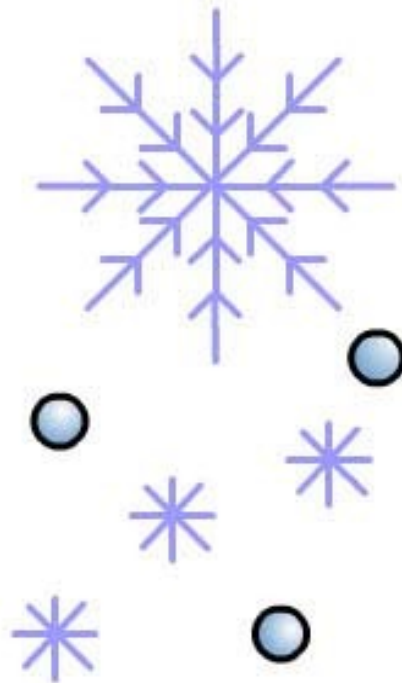


vapor is transported from the droplet
to the ice crystal

Cloud microphysics

- Once the crystal grows large enough it undergoes a process similar to collision-coalescence.
 - The crystal can collide with cloud droplets. If the cloud is colder than 0°C , the droplets will freeze on contact. (called riming)
 - The crystal can also collide with other ice crystals. This process is responsible for the formation of large snowflakes. (called aggregation)

Growth by Collision with Cloud Droplets and other Ice Crystals



Cloud Dynamics

*(Wallace and Hobbs, 1977;
Ahrens, 1999)*

- Types of clouds
 - Stratiform
 - May consist of water droplets and/or ice crystals.
 - Persist for great periods of time.
 - Droplets are all nearly the same size. (The same is true for the ice crystals in cold clouds).
 - Small vertical velocities.
 - Generally a layered, featureless appearance.



Cloud Dynamics

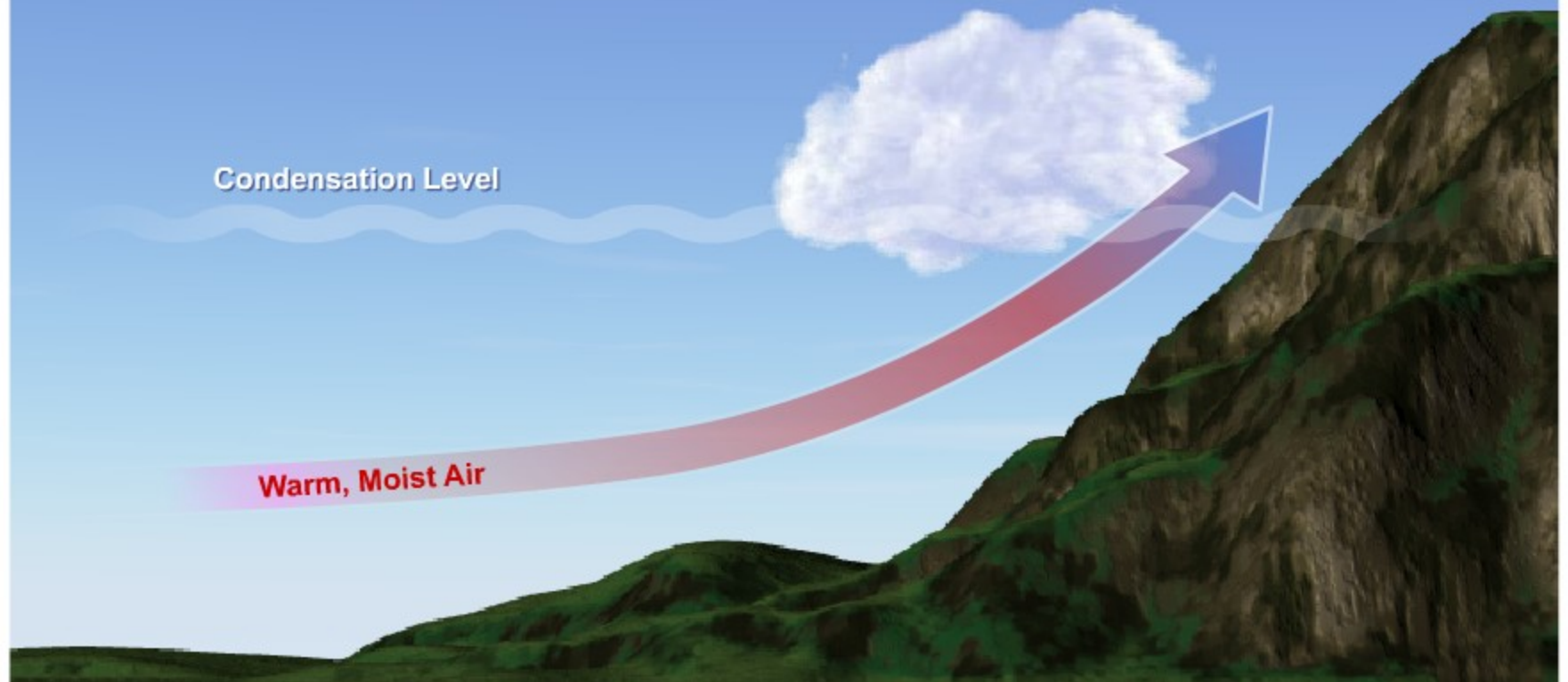
- Cumuliform
 - May consist of water and/or ice.
 - Short lived.
 - Consist of droplets of varying sizes (same for ice crystals).
 - Larger vertical velocities than stratiform clouds.
 - Contain more liquid water than stratiform clouds (more is available to form precipitation).
 - Larger vertical velocities increase residence time of droplets/ice crystals in the cloud.
 - Allow water droplets to grow to larger sizes which contain larger volumes of water.
 - Generally, a more rugged cauliflower-looking appearance.

Cloud Dynamics

- Topography and Clouds
 - Orographic clouds
 - Form due to forced lift up a mountain.
 - Stable environment - normally all vertical motion is induced only by the orographic barrier. Some convection may be embedded within the cloud.
 - Rising air is cooled adiabatically to its dewpoint and the cloud forms at the LCL.



Orographic Cloud Formation and Precipitation



Determine the processes associated with cloud formation and precipitation

Cloud Dynamics

- As the air flows over the mountain, adiabatic warming occurs with the descent and the cloud dissipates on the leeside of the mountain barrier.
- Vertical velocities can be as large as several m/s depending on the speed and direction of the wind component perpendicular to the barrier, and the height of the barrier.
- In steady winds, these clouds can persist for long periods of time (up to days).

Cloud Dynamics

- **Unstable environments** - normally all vertical motion is induced by the orographic barrier, but then parcels may continue to rise due to buoyancy
 - Rising air is cooled adiabatically to its dew point and the cloud forms at the LCL.
 - Forced stable ascent lifts parcel to its LFC (level of free convection), and the parcel now becomes unstable with respect to the surrounding environment (i.e., the parcel becomes warmer than the environment.
 - Vertical velocities can extremely large (10^2 of m/s) depending on the amount of instability.
 - In steady winds, these clouds can continue to form in the same location over long periods of time, resulting in extremely heavy precipitation.

Cloud dynamics

- Form due to mountain-induced lift at altitudes above the mountain top (sometimes, the lift occurs at altitudes well above the mountain top).

Cloud Dynamics

– Lenticular Clouds

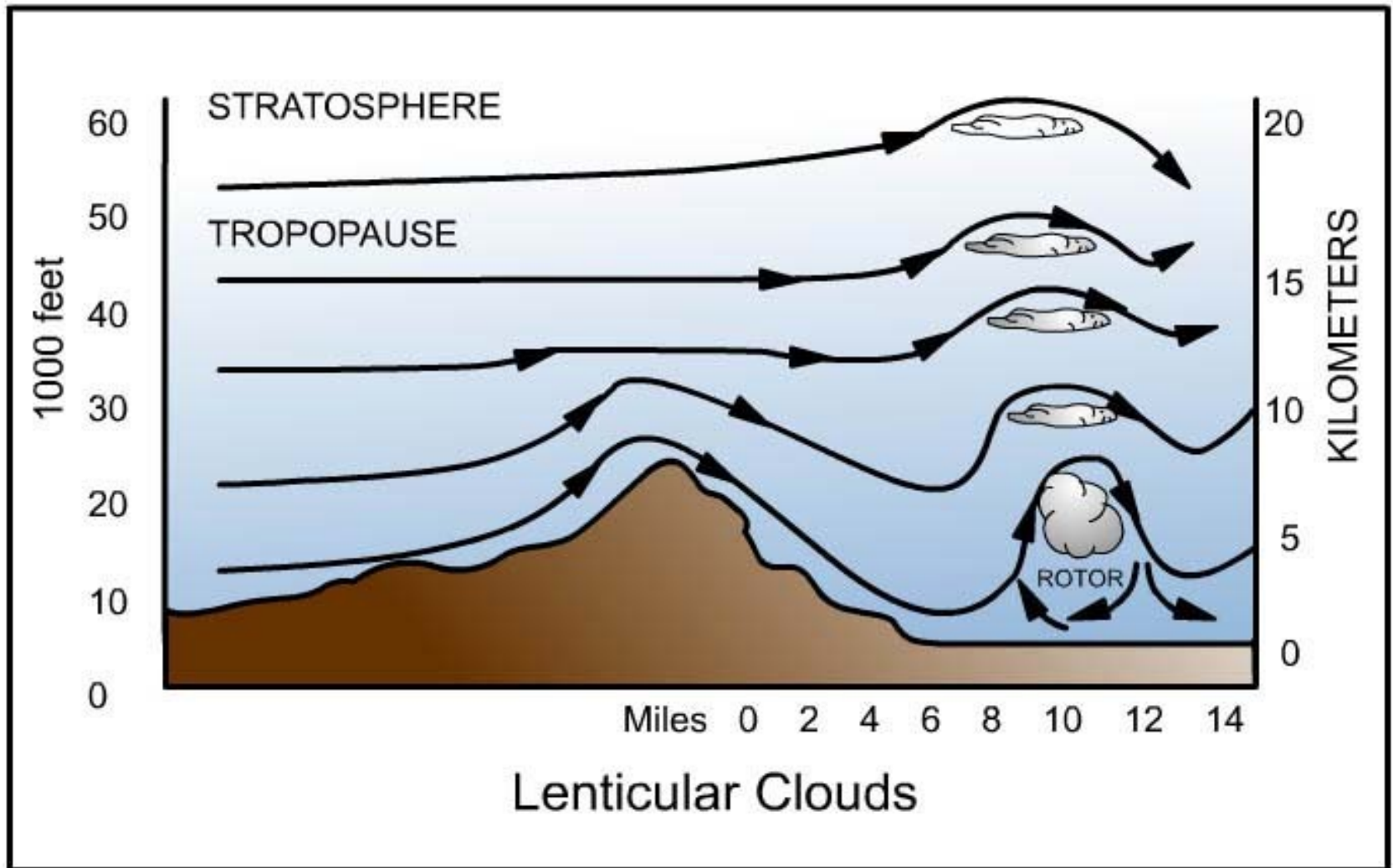
- Stable clouds
- Vertical velocities can be as large as several m/s depending on the speed and direction of the wind component perpendicular to the barrier and the amount of atmospheric disturbance induced by the mountains.
- In steady winds, these clouds can persist for long periods of time (up to days) Air flows over the mountains and waves for overhead and/or downstream.

Cloud Dynamics

- Lenticular cont.
 - Air is forced up in the vicinity of the peak, but only rises so high due to the stable atmosphere.
 - As it descends, it does so only to a certain extent, again due to the stability.
Note: A stable atmosphere suppresses motion both upward and downward.
 - Air parcels are bouncing or oscillating downstream.

Cloud Dynamics

- Lenticular cont.
 - **Clouds form in a lens shape**
 - As the air ascends, it cools and a cloud forms ($T = T_d$).
 - As it descends the cloud dissipates.
 - Can occur over or well downstream from the barrier.
 - **Also called standing wave clouds, standing lenticulars, or mountain wave clouds. A common abbreviation is ACSL for “Altocumulus Standing Lenticular”.**
 - **Often middle-level clouds (can be upper and even low-level clouds).**
 - **Indicates turbulence.**



Cloud Dynamics

- Lenticular cont.
 - Disturbances in the flow across the mountains can be seen to altitudes of 30 km. (These disturbances are associated with vertically-propagating gravity waves radiating from upward from the mountain.)
 - Isolated mountain peaks produce disturbances up to 2 to 3 km above the peak and lee waves do not persist very far downstream.
 - Rotor clouds - Farther downstream, near the surface, winds may switch directions, producing a rotation. This rotation produces a rotor cloud below the ACSL.
 - ASCL can be indicative of severe downslope wind events downwind of significant mountain ranges aligned somewhat perpendicular to the prevailing flow. This is a common occurrence at the US Air Force Academy in Colorado Springs, CO.

Cloud dynamics

- Lenticular cont.
 - High-base Convection
 - **Unstable Clouds**
 - **Forms due to elevated solar heating of the mountain surface.**
 - **Air in contact with the mountains becomes warmer than surrounding environmental air and rises upward.**
 - **If the rising parcel rises dry-adiabatically to its CCL (convective condensation level), then a buoyant convective cloud will form.**

Cloud dynamics

- Lenticular cont.
 - Vertical velocities can be extremely large (10's m/s) depending on the amount of instability.
 - In steady winds, these clouds will propagate downstream away from the mountain source region. However, new convective clouds may repeatedly form near the same elevated heat source (i.e., mountains) during the day.

Cloud Dynamics

- Shear induced wave clouds (billow clouds).
 - Caused by vertical wind shear (rather than an orographic barrier).
 - Generally mid- and high-level clouds; however they sometimes occur as low clouds.
 - Oriented perpendicular to the wind shear.
 - A stable cloud which forms in conjunction with a temperature inversion.

Cloud Dynamics

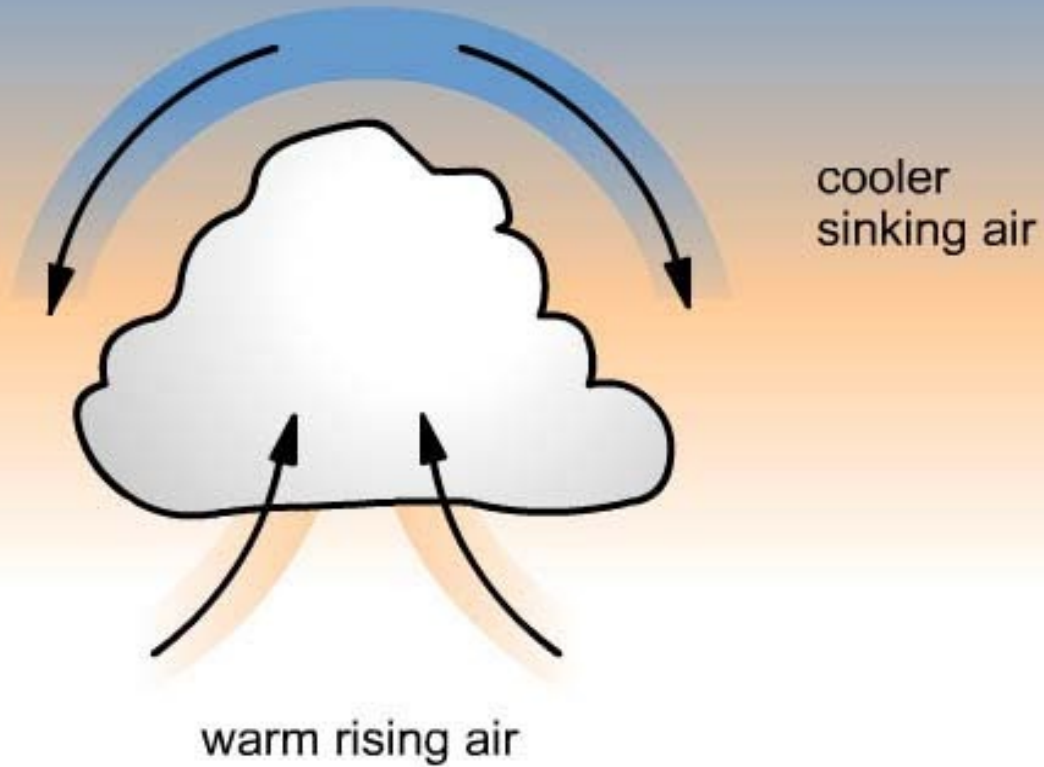
- Layered clouds - due to widespread ascent of stable air. Associated primarily with development of fronts and cyclones. (More in Dynamics.)
 - Region of surface low pressure. Low-level convergence forces air to rise and forms clouds (Stratus and Stratocumulus).
 - Warm Fronts - warm moist stable air rises up over colder air at the surface. (stable clouds from)
 - **Cirrostratus, Altostratus, Nimbostratus, and stratus normally form under these conditions.**



Cloud Dynamics

- Convective clouds (Cumuliform clouds)
 - Convection forms when an air parcel becomes warmer and less dense than the surrounding air. When the unstable rising air becomes saturated, a convective cloud forms. This cloud will continue to grow as long as air within the cloud remain buoyant.

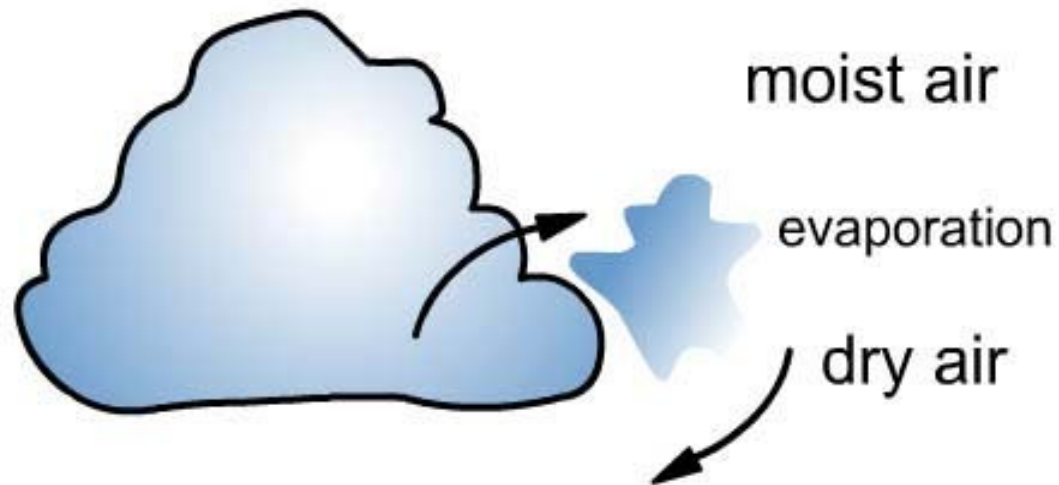
Convective Clouds



Cloud Dynamics

- Air motion is downward on the outside of the cloud.
 - Sinking air due to convective circulation - cooler air slowly descends to replace the warm rising air.
 - Dry air entrainment - Dry air on the outside of the cloud mixes with the cloud.
 - **Causes edges to appear sharp.**
 - **Causes subsidence - Heat loss due to evaporational cooling, makes the air parcels heavier and they sink.**
 - **Evaporative cooling of dry air entrained into the updraft reduces the strength of the updraft.**

Dry Air Entrainment



Cloud Dynamics

- Vertical extent (thickness of cloud) depends on:
 - **Atmospheric stability.**
 - **Moisture content of the air.**
- Convective clouds are produced from several different lifting mechanisms:
 - **Surface heating (either due to solar heating of the surface or colder air moving over a warmer surface) produces rising air parcels which reach their CCL. Also, differential heating of land and water across a coastline can produce convergence and lifting of warm moist air.**

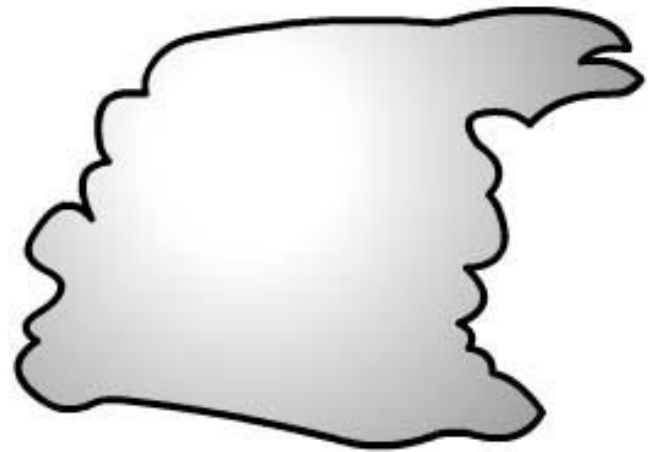
Cloud Dynamics

- Cold front - warm moist air forced upward to the LFC causes formation of a line of cumuliform clouds (Cu, TCu, Cb).
- Warm Fronts - warm moist unstable air rises up over colder air at the surface and is lifted to the LFC. (cumuliform clouds form). These cumuliform clouds can be embedded within extensive stratiform cloud fields, as those parcels reaching their LFC become convective while other parcels not attaining their LFC remain stratiform.
- Topography - mountainous can force convectively unstable air to rise to CCL or LFC (discussed earlier).

Stability and Cloud Development



stable



unstable

Cloud Dynamics

- Fog - a cloud with its base at the earth's surface. (Detailed information about forecasting fog formation is covered in Block II.)
 - Consists of small droplets suspended in the air.
 - Most fog is associated with a stable cloud (usually stratiform in nature small vertical velocities).

Cloud Dynamics

- Types of fog
 - **Fogs formed by cooling**
 - **Radiation fog** - due to radiational cooling of the earth's surface at night.
 - » Air near the surface is cooled to its dew point temperature by conduction as it comes in contact with the ground.
 - » Gradual mixing transports cooling effects to reach higher levels.
 - » Valley fog occurs as cooler air drains downhill into a valley.
 - » Forms best under good longwave radiation conditions (nights with clear skies, dry air aloft, and light winds).
 - **Advection fog** - warm moist air moves over a cold surface. (i.e., coastal fog or sea fog). Occurs when the air's dew point is higher than the underlying surface temperature. (stable)

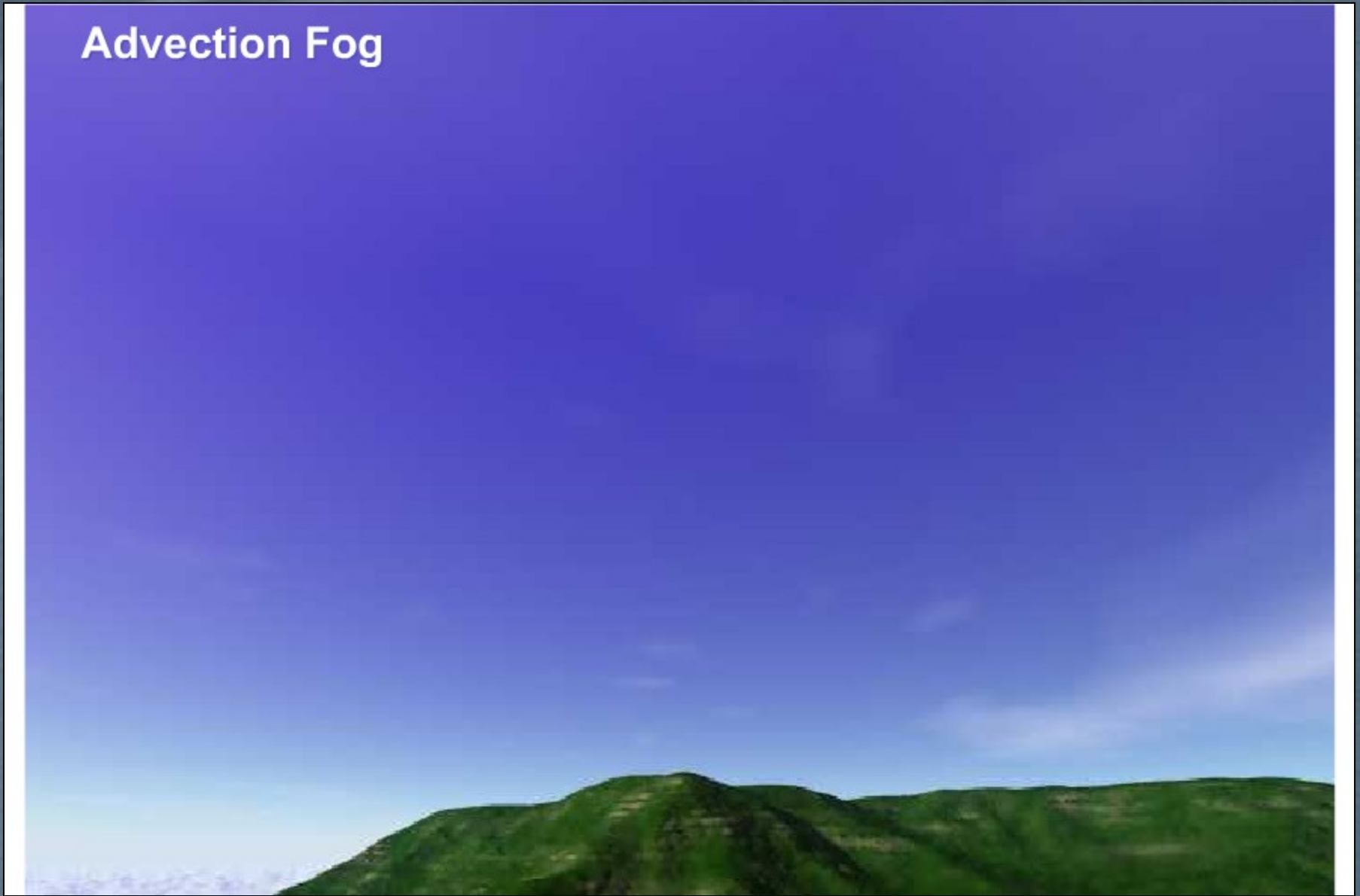


Radiation Fog



Determine the processes associated with cloud formation and discuss their

Advection Fog

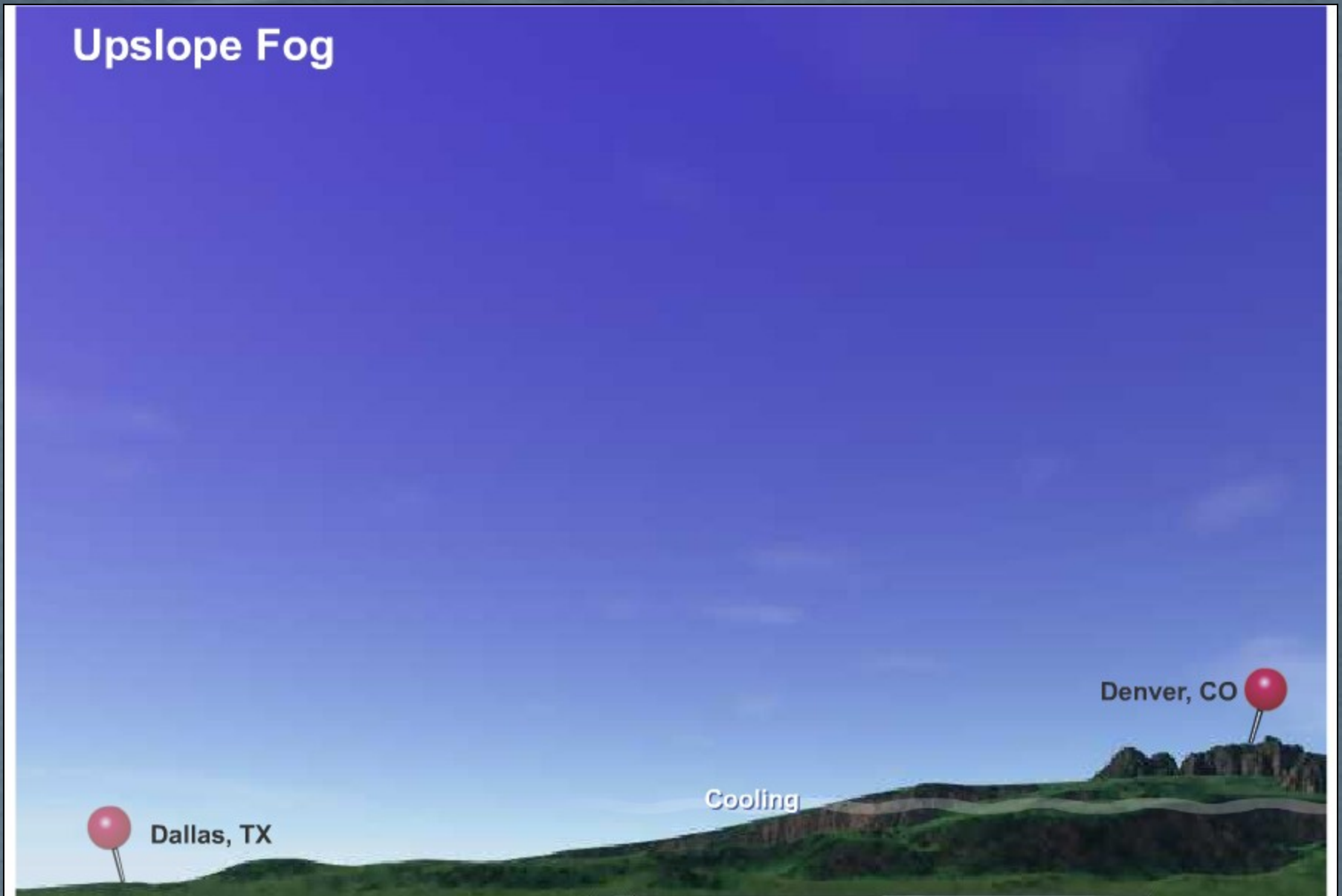


Determine the processes associated with cloud formation and dissipation

Cloud Dynamics

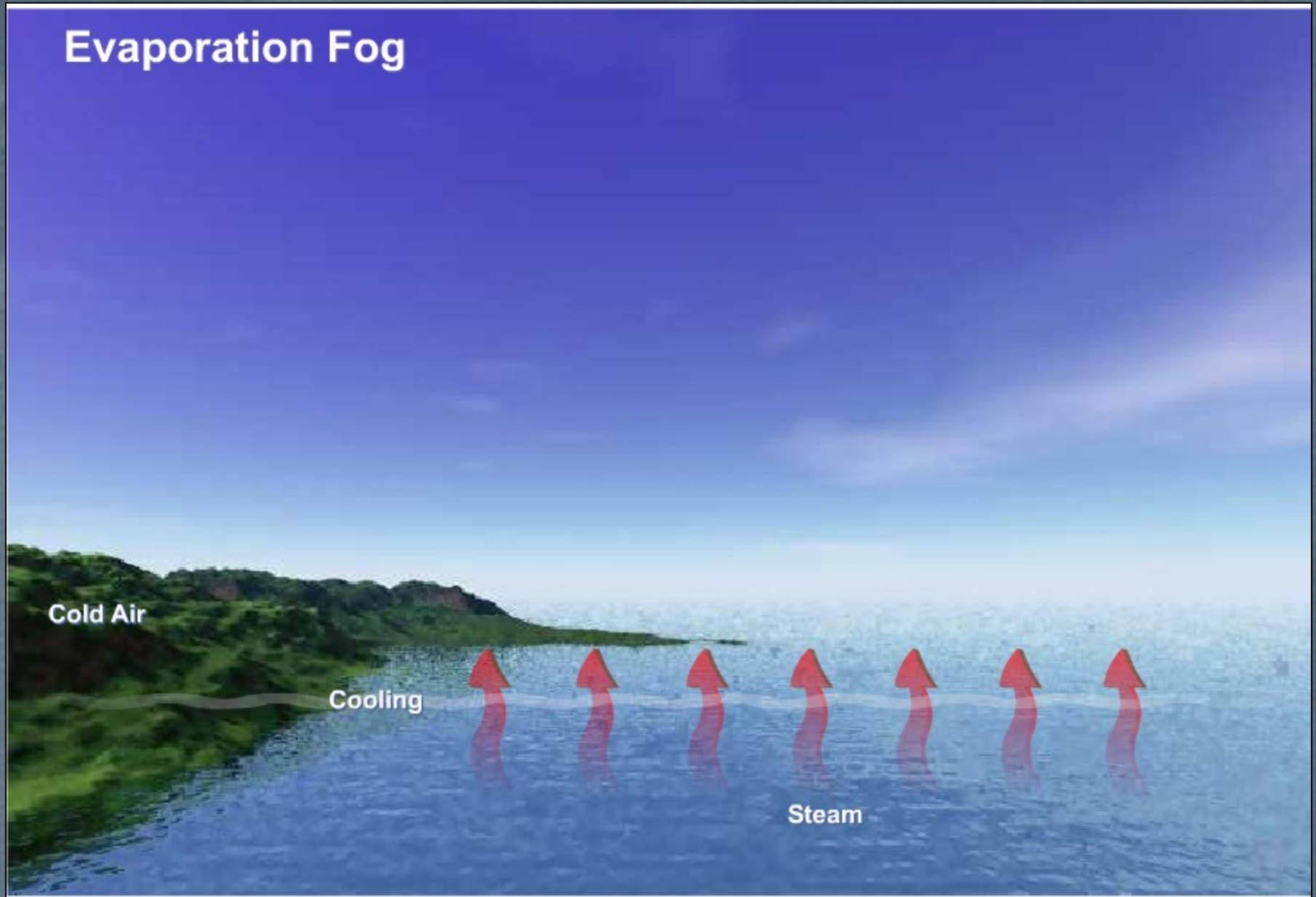
- Upslope fog- air is cooled (adiabatically) to its dew point as it moves up a barrier. (Similar to formation of orographic clouds.) (stable)
- Evaporation fogs
 - Evaporation fog - occurs with cold air moving over a warmer moisture source. (i.e., steam fog occurs with cold air moving over warm water.) (unstable)
 - Frontal fog - warm rain falls through cold air. The rain evaporates until the air becomes saturated and a fog forms. (common ahead of warm fronts). (stable)

Upslope Fog



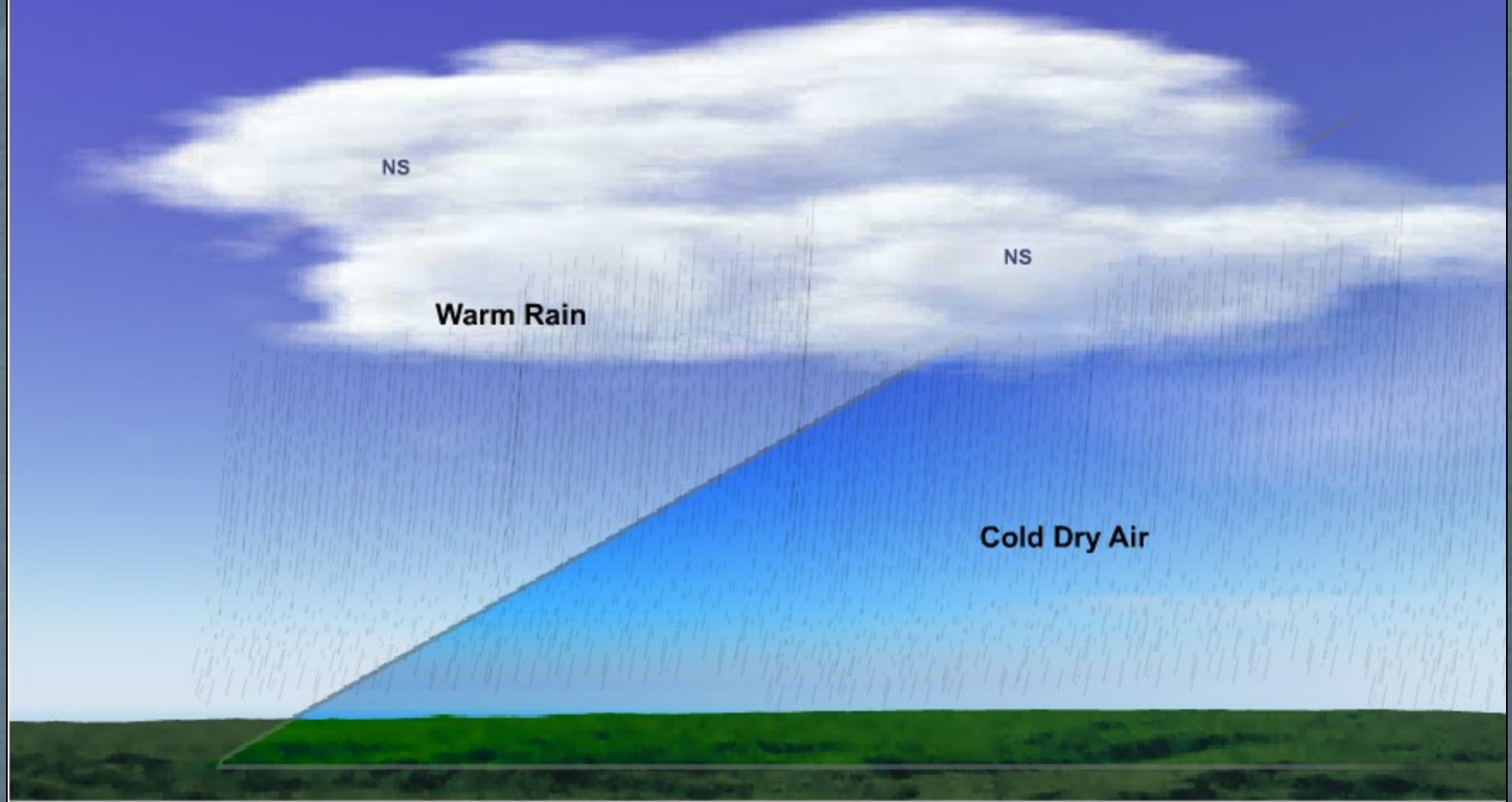
Determine the processes associated with cloud formation and dissipation

Evaporation Fog



Determine the processes associated with cloud formation and dissipation

Frontal Fog

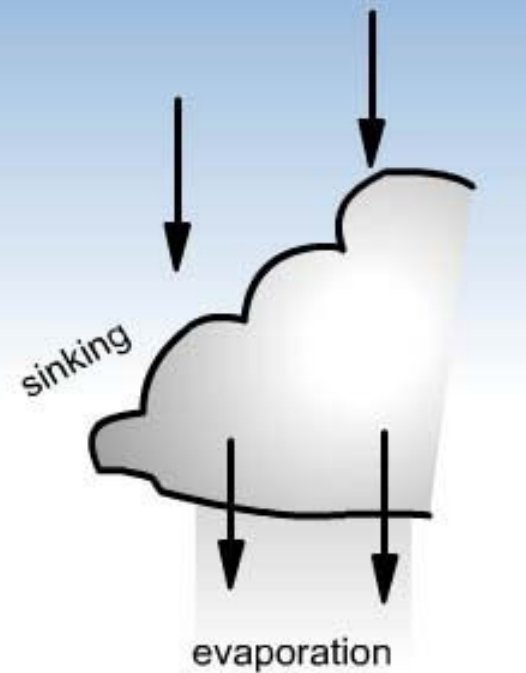
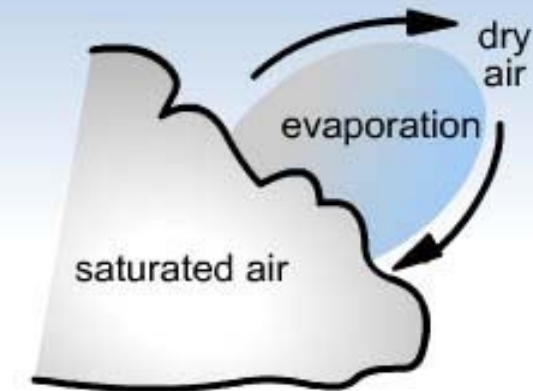


Determine the processes associated with cloud formation and dissipation

Cloud Dynamics

- Dissipation of Clouds - evaporation of water droplets and sublimation of ice crystals. Caused by 2 main mechanisms:
 - Decreased moisture
 - Precipitation falling out of the cloud
 - Dry air entrainment.

Dissipation of Clouds



Cloud Dynamics

- Increased air temperature
 - Adiabatic warming due to subsidence.
 - Warming from below (stable atmosphere)
- Lack of continued saturated air parcel ascent due to
 - Loss of a lifting mechanism
 - Increasing environmental stability

APPLICATION: Assign Review
Exercise in WB-100

EVALUATION: Administer and
evaluate Appraisal 104e. Give the
written test at the end of the unit.

